LASER TRIGGERED SWITCH RESULTS FROM A FREQUENCY QUADRUPLED ND:YAG LASER*

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Summary

A 3 MV modified PBFA trigatron switch has been successfully triggered by the 266 nm UV beam of a Nd:YAG laser in a water-insulated transmission line test facility. Focusing the 2 ns FWHM 25 $\pm$ 5 mJ laser pulse into the 65 psig SF_6 atmosphere, triggered the switch gap from 69% to 90% of the self-break voltage ($V_{SB} \approx 2.3$ MV). The characteristic linear slope is less than 5 ns per 10% of V_{SB} with closure delay times less than those of the 20 ns KrF laser at twice the energy. Two data points deviating from the rest of the set increased the one-sigma jitter from 1.5 ns to 3.9 ns. More LTS data have been collected after the addition of a second trigatron which is also laser triggered. Jitters of 2.3 ns and 1.5 ns were measured for laser energies of 20 mJ or less. The initial implications are that a single 150 mJ Nd:YAG laser can satisfactorily trigger five or more switches to achieve low jitter between the modules of a particle accelerator as well as other large pulsed power devices.

Introduction

Laser triggering of high voltage gas insulated switches is not a new concept,[1,2,3,4] but its application to large pulse power devices has only recently taken place at Sandia National Laboratories. Work has been published by several authors who utilized a KrF laser to trigger gas switches.[5,6,7] At Sandia, we have been concentrating on triggering of SF_6 filled switches with UV light at 248 nm.[7] More recently we have investigated triggering at 266 nm with a short pulse quadrupled YAG laser.[8] We have endeavored in this paper to study the triggering characteristics produced by a particular quadrupled YAG laser interacting with a 3 MV switch. The advantages of laser versus electrical triggering include lower jitter, reduced prefire probabilities, increased electrode lifetimes, and reduced energy losses.

The experiments consisted of three segments which were performed to assess the suitability of the short pulse quadrupled YAG for triggering the gas switches with RMS jitters of less than 4 ns. The first segment was aimed at establishing the salient laser performance parameters. The second segment was the demonstration, on a single switch, that the laser energy from one 150 mJ YAG was sufficient to trigger five switches. The third segment involved the triggering of two switches simultaneously.

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Laser Performance

Some important laser parameters of the Quanta-Ray DCR II laser which was modified to give increased energy output were measured in a separate experiment. The experimental setup is depicted in Fig. 1. The beam was attenuated by multiple interaction with quartz plates. In this experiment, we measured the shot-to-shot repeatability of energy, pulse shape, and timing of two lasers triggered by a common command fire signal. The energy of each laser was monitored by two calorimeters. The temporal pulse shape of both lasers was measured with a fast UV-sensitive photodiode which had a rise time of 0.3 ns. The output from the photodiode is shown in Fig. 2 and was recorded by a 1 GHz oscilloscope. Each pulse is actually composed of three pulses separated in time by 4 ns. This pulse shape was adjusted to resemble those of Fig. 2 in order to minimize the energy in the first pulse and maximize that of the second. The two laser pulses were delayed from each other by about 23 ns and both were directed onto the single photodiode. Twenty-one measurements of energy and relative jitter were performed about every ten minutes over a 3-1/2 hour period. During this period no adjustments were made on either laser. The 1-σ relative jitter between laser pulses was measured to be slightly less than 0.2 ns. The average energy of one laser was 156 mJ, and the other was 157 mJ, while the standard deviation was 5 mJ and 4 mJ respectively. The full width at half maximum of each laser pulse was about 2 ns. After these experiments were performed the manufacturer of this laser upgraded its energy output to 300 mJ in the fourth harmonic.

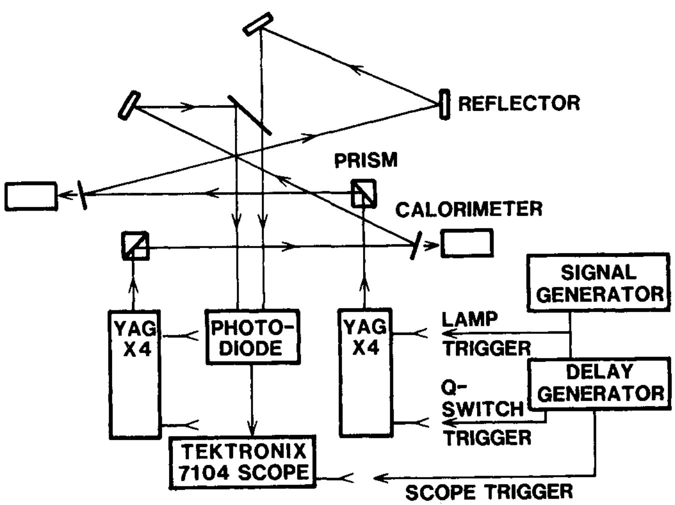

Figure 1. Simultaneity test of two quadrupled YAG lasers

The Triggering Scheme

The collimated 266 nm beam leaving the YAG laser is guided to the gas switches via an arrangement of reflectors and a beam splitter similar to that shown in Fig. 3. Relative timing between the switches can be adjusted by varying the optical path lengths

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in either route following the splitter. The beam enters the switch by first passing through a long focal length lens and then a UV grade quartz pressure window which separates the 5 Atm SF_6 environment from the ambient air. It travels through the plastic laser guide tube shown in Fig. 4 and through a hole in the uncharged electrode before focusing in the region between electrodes. The switch is a slightly modified PBFA trigatron with an 11.5 cm gap spacing.[9] Its negatively charged electrode is tied to an intermediate storage capacitor which is charged by a 1-cos ωt waveform in approximately one microsecond before being triggered. Upon closing, the switch charge transfers from the intermediate storage capacitor to a tri-plate pulse forming transmission line in the same water tank. Both the intermediate storage capacitor and the pulse forming lines are monitored by dV/dt capacitively coupled probes that yield the breakdown voltage data and the time at which the switch began conducting significant current. This is compared to the time of the laser pulse as monitored by a photodiode near the laser. Accounting for the differences in the cable and optical path lengths one can then measure the relative closure delay time within each switch with respect to the initiation of the laser ionizing spark. Examples of the timing data are shown in Figs. 5 and 6. The laser energy actually triggering the switch is estimated by measuring the beam entering the guide tubes with an energy meter and assuming additional losses of 7% for each uncoated lens and window in the tubes.

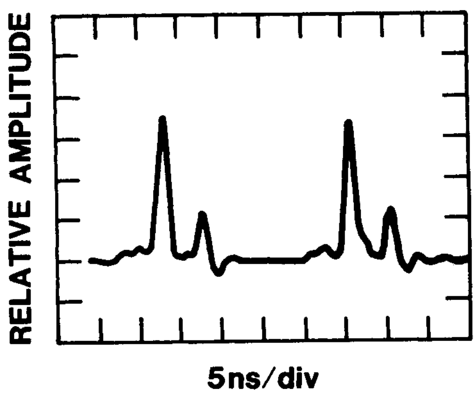

Fig. 2. Resulting pulse shapes for the two-YAG tests

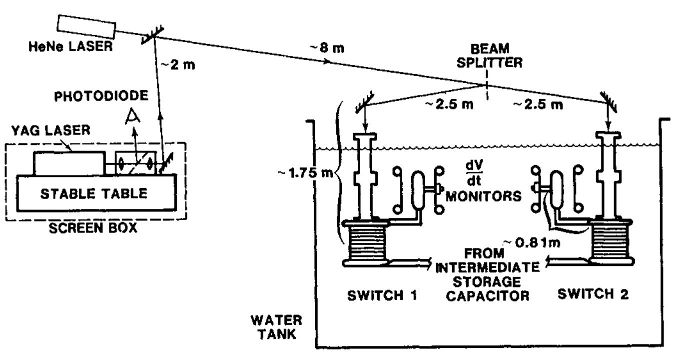

Fig. 3. Example of optical set-up for triggering two switches

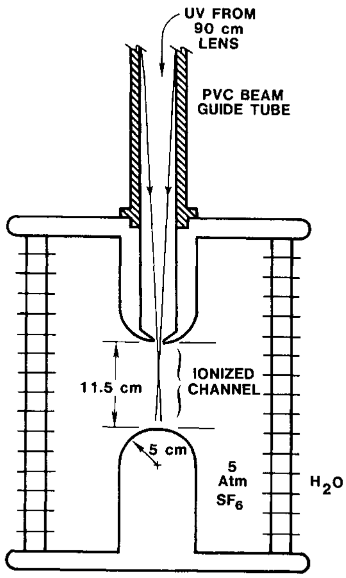

Figure 4. Focusing technique for creating the ionize spark channel

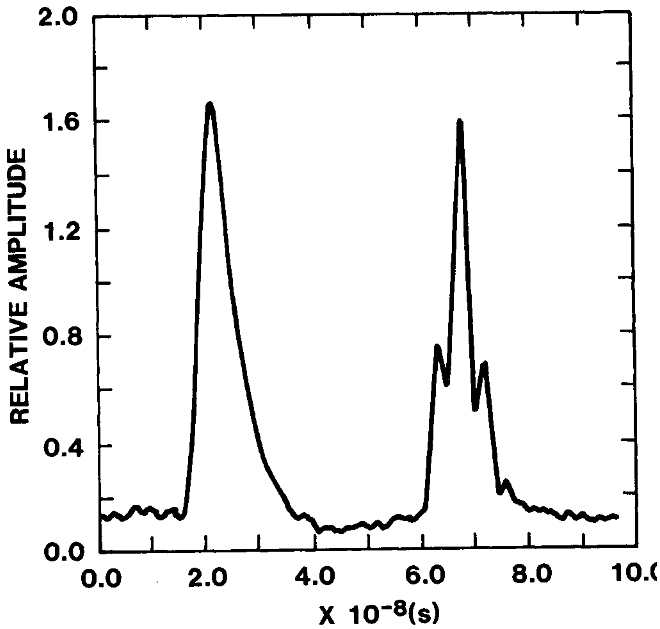

Figure 5. Typical laser pulse preceded by a fiducial signal

Experimental Results

The results acquired from triggering a single switch are shown in Fig. 7, where the relative switct closure delay is plotted as a function of the percent of the switch self-break voltage, V_{SB}, at which breakdown occurred. Using linear regression by the method of least squares, a straight line can be fitted to the data. A small slope of 10 ns/V_{SB} or less is desirable for good control of switching time: The two plotted points that seem to deviate from the trend could not be justifiably removed from the data set; and hence, the one standard deviation jitter about the fitted curve was degraded from 1.47 ns for the lower dashed line to 3.86 ns for the solid line. The previously reported KrF laser results (20 ns FWHM, 248 nm) fell into the region near the upper dashed line for comparison.[10]

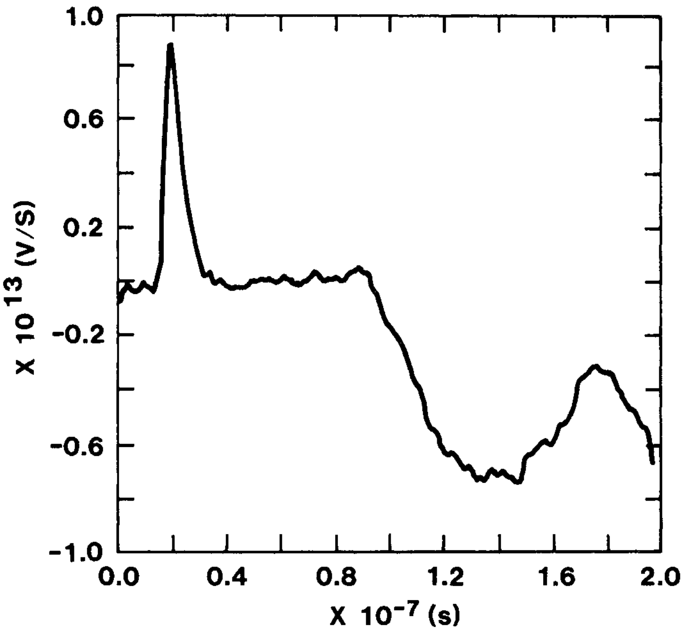

Figure 6. Typical $\dot{V}_{PFL}$ signal preceded by a fiducial reference

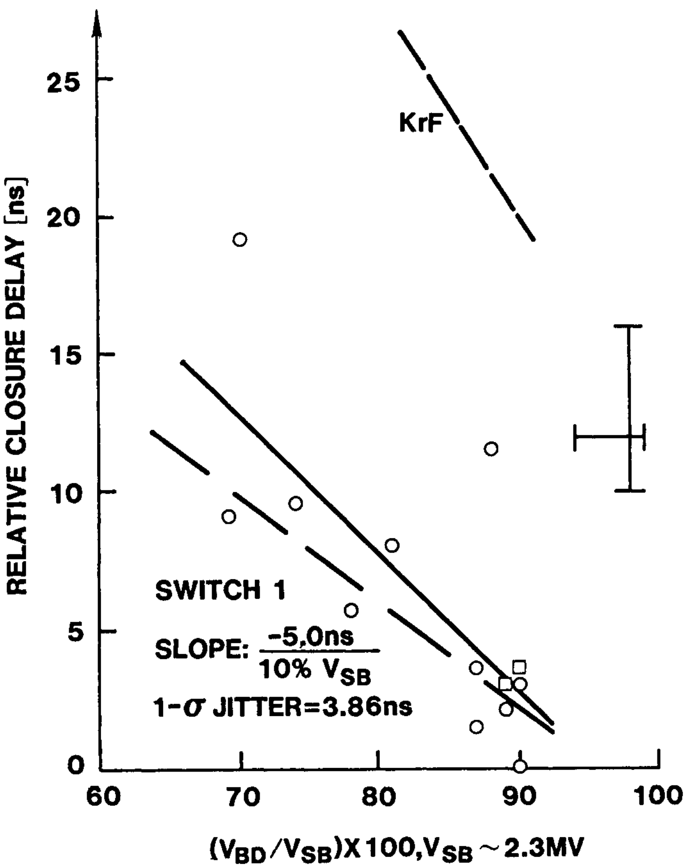

Figure 7. Single switch triggering results

Some major modifications were incorporated in the water tank of the test facility, affecting the loading on the intermediate store and adding a second laser triggerable switch. Thus, a second set of data has been accumulated using a common laser pulse to trigger both switches. The two curves of Fig. 8 have been fitted to the new data set. Note that the voltages are referenced to the peak of the charging waveform instead of the self-break voltage. The machine modifications changed the stray capacitance affecting the charging waveform such that the peak and self-break voltages agree to within 5 percent. The machine changes have affected the charging waveform enough to produce an apparent increase in the slopes of both switches. The comparable jitters of the first and second switches are 2.30 ns and 1.53 ns, respectively. This is very similar to the two-switch experiment reported for the KrF laser. A distinction from the KrF simultaneity jitter between switches is the higher 2.76 ns jitter. This is probably explained by the larger difference in the slopes of the two switches as well as the recent machine reconfiguration. The improved performance of switch 2 over switch 1 may be justified by one or all of three reasons. The primary contributor is likely the fact that the switches see slightly different charging waveforms due to their location in the water tank. Another explanation is that the second switch receives about 16% more laser energy because the beam splitter is not exactly a 50:50 splitter. A final contribution stems from an addition of 10.5 ns of optical path length to the second switch resulting in a somewhat higher f-number for the not-quite-collimated beam. Additional data will be required to support or negate these conclusions.

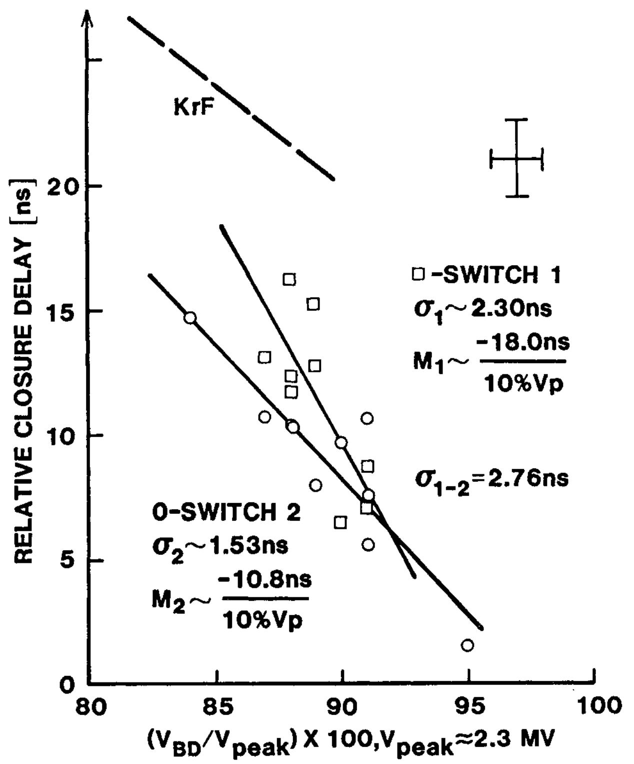

Figure 8. Double switch triggering results

Conclusion

The short pulse quadrupled YAG has been demonstrated as a highly reliable laser for triggering 3 MV class SF_6 filled switches. The jitter for such switches irradiated with approximately 20 mJ of 266 nm radiation has been shown to be about 2 ns for charge voltages in the range of 80 to 95% of self break. A single laser with an output of 250 mJ should

be capable of triggering as many as 5 or 6 of these switches, with allowance made for as much as a 50% loss of optical energy in the beam train. In addition, because of the demonstrated low jitter of less than 0.2 ns between lasers, this source of coherent UV radiation is easily extendable by simply adding more laser modules in parallel. Therefore, one has the capability of causing numerous high-voltage events to take place with minimal jitter.

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Note: The use of the Quanta Ray Laser in these experiments should in no way imply Sandia Laboratories preference of this product over any product with similar operating characteristics.